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*ON SOME FUNDAMENTALS OF PRE-CAMBRIAN PALEO-
GEOGRAPHY*

BY RUDOLF RUEDEMANN

NEW YORK STATE MUSEUM, ALBANY, N. Y.

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It is an established fact that the Archean basement complex (representing the Archeozoic era) has undergone not only complete metamorphism but also a world-wide intense folding which undoubtedly is a true folding due to world-wide diastrophism. The later Pre-Cambrian rocks (classed formerly as Huronian, then as Algonkian and more recently as Algoman, Huronian and Algonkian rocks, representing Proterozoic time) have escaped metamorphism and folding in the interior of North America but elsewhere have undergone like folding as the Archean basement complex and with few exceptions in the same sense; for example, in the eastern Canadian shield, where both are folded from the southeast (Adams). This world-wide folding of the Pre-Cambrian rocks stands in striking contrast to the localized folding of the earth crust in all later time.

Starting from this fact of the complete folding of the exposed Archean areas and on the proper inference that the entire Archean basement complex, and with it the greatest part of the Proterozoic rocks of the Earth, is likewise folded, the writer has attempted a synthesis of the directive lines of arrangement of these Pre-Cambrian folds.

In such an attempt there are to be excluded:

1. All areas of metamorphic rocks which are either proven to be or suspected of being younger than Pre-Cambrian age; such as are found in Greece, Asia Minor, the Andaman and Antillean Islands (serpentines of Cuba, etc.), the gneisses of the Coast range, lower California, etc.

2. All rocks of Pre-Cambrian age involved in Post-Cambrian folding, as those of North Africa, Spain, France, western Germany, the Alps, eastern Australia, etc. But it is to be noted here that even in these cases, keen observers have often enough found that the Pre-Cambrian nuclei of mountain ranges retain an independent original direction of folding, and further that

in some cases the new folds have clearly followed old lines of folding (post-humous folds). There are further left, even in those regions that were overrun by the crustal waves of Post-Cambrian time, 'islands' or blocks that remained undisturbed and that give important information on the original direction of folding in the Pre-Cambrian basement complex. Such undisturbed blocks are found in the Rocky Mountains, in Bohemia, on Borneo, in Cambodia, etc.

The large areas that are then left and lend themselves to our inquiry, are the greater part of North America, small regions of South America, eastern Europe, northern and eastern Asia, all inner Africa and western Australia. The general facts gleaned from them are complemented by those obtained from the unfolded 'islands' or blocks.

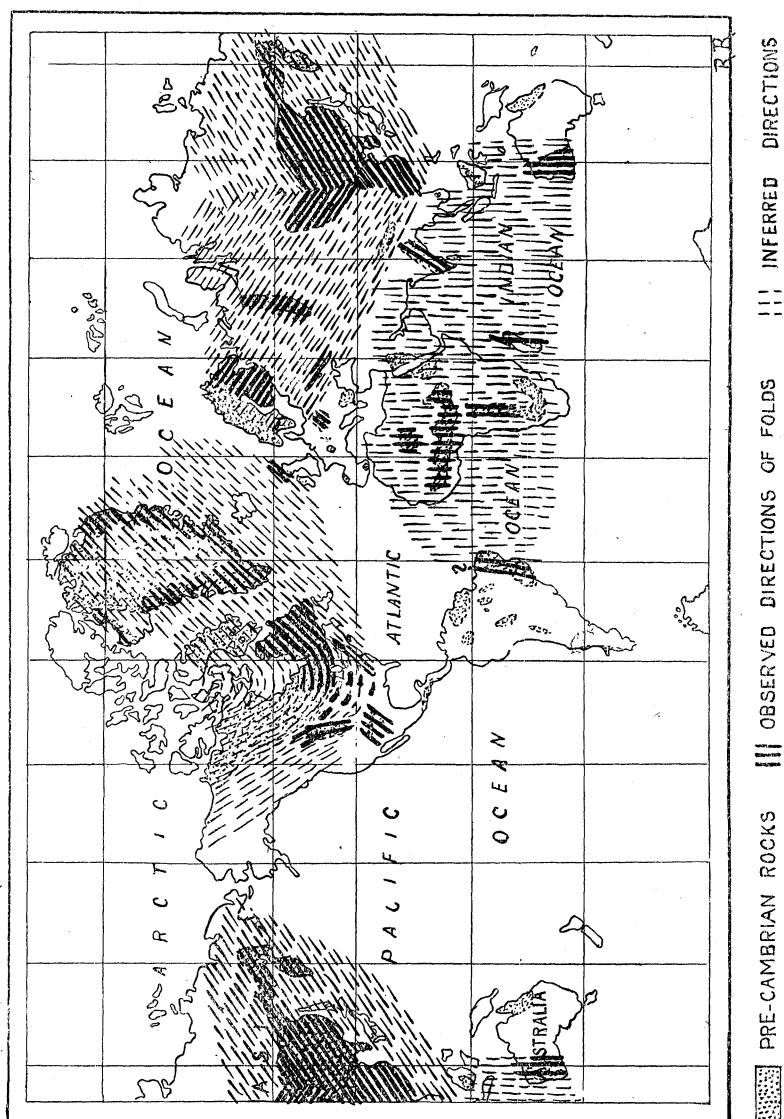
The most important of these areas are the so-called continental nuclei of North America (Canadian shield), Europe (Baltic shield) and Asia (Angara shield). An intended comparison of their principal directions of folding presupposes essential contemporaneity of the diastrophic revolutions they have undergone. This has been established by the correlations carried out by Adams, Sederholm and Willis. It is also to be noted that evidence of a like succession of eras and diastrophic events has been found in most of the other regions here mentioned as being amenable to our inquiry.

The source for this inquiry is chiefly Edward Suess' *The Face of the Earth*, where there is not only a large store of information as to the directions of Pre-Cambrian rock folding but where also the facts of the general directions of Pre-Cambrian folding in Asia and eastern Europe are clearly set forth. Nevertheless the assembling of the full data on Pre-Cambrian folding, which will be given in a later publication, requires laborious search through a widely extended literature.

With these introductory remarks we may briefly survey the preliminary results (which undoubtedly are still subject to important corrections) as to the arrangement of Pre-Cambrian folds.

In China, Richthofen, Pumpelly and Willis have found a uniform NE direction in the basement complex, which was completely folded and again abraded before the Cambrian submergence. This NE direction (the Sinian system of Richthofen and Pumpelly) continues through Korea, and Suess has shown its complete domination in all northeastern Asia east of Lake Baikal (his 'Baikal direction'), which is ENE-NE. This meets, in a meridional line, the 'Sajan direction' of Pre-Cambrian folds, which is WNW to NW and prevails west of Lake Baikal through all northern and middle Asia, Russia (Karpinski) and the Baltic shield, the latter being only a larger northern exposure of the Russian Pre-Cambrian plate. The latter extends through northern Europe much disturbed by later folding and probably abuts against the Laurentian plate in western Scotland.

In North America the Canadian shield exhibits in its eastern portion a uniform NE direction of the folds (Adams and Coleman). This direction



continues through Greenland with some variation to NNW along the coast of Labrador through Tertiary crustal movements (Adams) and it is even recognizable in the western edge of Scotland. It is further observed in several ways, as in the interlocking NE-SW bands of different gneisses, showing ancient folding (Keith) in the southern extension of the Pre-Cambrian basement complex in the Appalachian and Piedmont systems. In the western part of the Canadian shield, north of Lake Superior, the Pre-Cambrian folds have assumed an E-W direction. Likewise the outcrops of Pre-Cambrian rocks south of Lake Superior in Wisconsin etc. show a predominant E-W direction. In the Ozark Mountain Pre-Cambrian nucleus however, a NW direction (strike N 50°W) is already recognizable; likewise in the Black Hills and farther south in the Arbuckle uplift in Indian territory (strike WNW) and in Texas, in Burnet county; where a monadnock of the ancient Laurentian land projects with a NW strike of the major folds in the Pre-Cambrian rocks. In the southern Rocky Mountains the Pre-Cambrian masses strike from S to N but exhibit a tendency to turn NNW to NW.

It thus appears that there can be recognized in the Pre-Cambrian base of North America a uniform structure consisting of a NE system of folds in the east, that however does not abut, as in Asia, against a NW system, but gradually swings into it.

In Africa large areas of the Pre-Cambrian basement complex are exposed in the Sahara Desert and south, throughout Central Africa to the Red Sea and across it into Arabia. In the Sahara and western Africa as far as the Kalahari Desert, the strike of the folds is reported to be uniformly N-S, as far as known today, with variations in the east to NNW etc. Likewise in West Australia the direction of the folded areas of metamorphosed Pre-Cambrian rocks is N-S with a slight trend to W; and, as far as we could find, the northerly direction is also present in Madagascar with variations to NE. It thus appears that there was a third immense tract of uniform Pre-Cambrian folding extending from West Africa to Australia.

There are a number of smaller areas of Pre-Cambrian rocks known that have not been folded since Pre-Cambrian time. These are in Asia, found in Cambodia, Borneo and India. The latter shows in the Arvali Mountains Pre-Cambrian folds striking NNE (N 36°E) and extending within 65 Km. of the Himalaya Mountains which from the north have overridden the Pre-Cambrian Mountain system. Farther south there is also a younger group (Algonkian?) of folds with E-W direction. These Indian Pre-Cambrian folds, especially as seen in the Arvali Mountains, are entirely distinct from the Asiatic system and probably referable to the African system. There is likewise in Bohemia a Pre-Cambrian complex, striking NE for the most part, that is independent of the Russian plate and the Baikal direction. In America the Colorado mass, exposed in the Grand Canyon and south, represents a body of Archean and Algonkian folds with a NE direction and distinctly outside of the Laurentian system of North America.

In South America, NW to W striking folds in rocks of Archean aspect north of the Amazonas and in middle and western Brazil are all of younger than Cambrian age. It is however possible that the N-S (NNE) direction of the folds of Archean rocks in the Sierra do Mar and S. de Mantigueira in eastern Brazil can be correlated with the N-S folds in Africa and Australia. In Argentina, south of Buenos Ayres, mountain ranges composed of granite and gneiss with a SE strike represent, according to Suess, a continuation of the Brazilian basement complex.

The Antarctic Continent has afforded rocks of Archean aspect and may represent another shield; so far, however, these rocks have been found only in loose blocks.

The most important fact standing out from these data is that of the existence of at least three vast areas of Pre-Cambrian rocks of a supercontinental order of size, with uniform structure. One of these comprises Eurasia, exclusive of India and parts of northern and middle Europe; another Africa, West Australia and possibly India and eastern Brazil; the third North America with Greenland and the North Atlantic region to the Shetland Islands, but probably exclusive of the Colorado nucleus.

It will be a matter of further inquiry whether these wide tracts of supercontinental size that responded as units to the diastrophic forces that mark the world-wide Archeozoic and Algonian revolutions are to be considered as the first expressions of the gigantic continents that we find in Paleozoic time in the sense that they are ancestral or arch-continents. Indeed they well correspond to the later continents, as seen in the north Atlantic extension of North America across Greenland towards Europe; the Afro-Australian continent (Gondwanaland) and the Eurasian continental mass of Paleozoic times (see paleogeographic maps by Lapparent, Frech, etc.); the oceans that now separate the continents having arisen by a gradual collapse of the earth crust, probably along great circles.

There is, however, this further possibility to be considered; that the NE and SE Pre-Cambrian fold systems of Eurasia and North America form one belt and the N-S fold system of the equatorial regions in Africa and Australia another one. In that case we should have, on the northern hemisphere, surrounding the North Pole, a continuous belt that consists of two pairs of directions, each composed of a NE and NW striking system of folds; the whole forming a zigzagged belt; and another belt of N-S folds approximately following the equator. Between the two belts lie the independent blocks of India, Bohemia, Colorado, etc., all, or most of them with a NE direction as if, in some way, leading from the equatorial belt up to the circumpolar belt. It will probably have to be left to future observations whether there are indications of a corresponding circumpolar belt on the southern hemisphere as slightly suggested by the occurrence in Argentina.

If these belts actually exist as sketched here (see chart), then the question arises whether they do not represent cosmic agencies that influenced the

whole earth crust. There come to mind the suggestions of George Darwin as to the possibility of tidal waves in the earth crust as orogenic forces that would cause an equatorial N-S direction in the folds and a NE direction in the northern hemisphere; and those of Douvillé and Prinz who would explain, one the prevailing E-W, the other the N-S directions of many of the mountain ranges of post-Proterozoic time by a former greater velocity of revolution (Suess). It would seem that these belts of Pre-Cambrian folds lend themselves still more readily to an explanation by one or the other of these factors than do the post-Proterozoic more local fold systems. Since the Pre-Cambrian folding both in America and Eurasia has a southerly component (thrust from SE and SW), a retardation of the revolution of the Earth and a resulting wandering of the crust towards the poles seems to be indicated.

On the other hand, it must also be asked whether the world-wide folding of the Archean basement complex could not be explained by simply terrestrial forces. In this connection the result of close mapping of the Pre-Cambrian folds, carried out in late years in Bohemia and Scandinavia is of great importance. It brings out closely compressed folds, whose strikes are tortuous and wavy curves and often subcircular and even angularly broken lines. This, it has been concluded, points to a tangential pressure, acting from all sides on an earth crust of fairly uniform composition (Uhlich), a pressure and a composition that could be found only in Pre-Cambrian or rather Archean time, and that means a uniform contraction of the entire earth crust such as could not be invoked for the post-Proterozoic mountain systems. If this view should supply a competent explanation for the world-wide Archean folding, it still leaves unaccounted for the presence of large systems of uniform folding, which, as we have already seen suggests the view that in Proterozoic and even in Archeozoic time the crust was separated into masses that correspond in position if not in area and configuration to the continents of Paleozoic and more recent time.

THE INORGANIC CONSTITUENTS OF LOBSTER SHELLS

BY FRANK WIGGLESWORTH CLARKE AND GEORGE STEIGER

U. S. GEOLOGICAL SURVEY, WASHINGTON

Read before the Academy, November 18, 1918

In the course of an extensive investigation relative to the inorganic constituents of marine invertebrates, by Clarke and Wheeler,¹ it was found that among the distinctly magnesian organisms the proportion of magnesia was dependent upon the temperature of the water in which the animals live. The cold water animals contained much less magnesium carbonate than those